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THE APPLICATION OF MATHEMATICAL METHODS IN AVIATION AND SPACE MEDICINE

CONFERENCE, MOSCOW, FEBRUARY 25-26, 1965 (SUMMARY OF REPORTS)

by K. A. Ivanov-Muromskiy, et al.

Akademiya Nauk SSSR, Voyenno-Vozdushnyye Sily, Moscow, 1965.

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THE APPLICATION OF MATHEMATICAL METHODS IN AVIATION AND SPACE MEDICINE, CONFERENCE, MOSCOW, FEBRUARY 25-26, 1965. (SUMMARY OF REPORTS)

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THE APPLICATION OF AN ELECTRONIC DIGITAL COMPUTER FOR ANALYZING THE BIOELECTRIC ACTIVITY OF THE BRAIN DURING EXCITATION AND INHIBITION

K. A. Ivanov-Muromskiy, S. L. Sapozhnikova,
N. Litvin and K. S. Ganchukov

The interpretation of the physiological state of the human and /3* animal brain is based primarily on the frequency-phase analysis. The low percentage of information utilization obtained with present day experimental setups, as well as subjectiveness and a substantial expenditure of time to interpret information are characteristic of the visual analysis of EEG's. The use of special equipment for automatic analysis (integrators, analyzers with different types of filters), in addition to experimental difficulties, is associated with definite limitations. The development of biomedical electronics has shown a unique prospect for utilizing the electronic computer for extracting a maximum amount of useful information, for studying bioelectric processes under dynamic conditions and for obtaining data rapidly (V. A. Kozhevikov, R. M. Meshcherskiy, 1963). It is assumed that the application of the electronic computer may reveal new laws associated with brain activity (W. Adley, 1961).

At the present time autocorrelation and cross-correlation methods of analysis are widely used in physiology and medicine. These methods make it possible to find the periodic components of the process and their parameters and to determine the stability and degree of static coupling of biopotential oscillation of various structures (K. Sato, 1957; M. Brauer, 1960; N. N. Danilova, 1963, 1964 and others).

The authors used the programs developed at the Institute of Cybernetics of the AN UkSSR for correlation analysis by means of an electronic digital computer. The data were prepared by the quantization of continuous EEG recordings and the measurement of the ordinates on both sides of the zero /4 line (this was done manually by projecting the film on a large screen and automatically by using a device developed at the computer center of the Institute of Cybernetics of AN UkSSR). In accordance with Kotel'nikov's theorem, the value of the division step was selected equal to 200.

*Numbers given in the margin indicate the pagination in the original foreign text.

Because correlation analysis does not account for rapid dynamic changes and for the phase of the oscillations, the authors made an attempt to supplement it with a periodogram method, which has been shown to have a series of advantages (Ye. Ya. Voytinskiy, O. M. Lebedev, M. V. Levin, I. N. Mutsin, 1963). The program developed for the electronic computer evaluates the frequency spectrum and the phases of oscillations. It is also suitable for interpreting electrocardiograms and myograms.

To produce different physiological states of the central nervous system, the brain of rabbits was subjected to current pulses of 100 and 1000 cps generated by equipment of original design. The investigation of the biopotentials of the brain structures, when these are subjected to current pulses, is very significant in establishing theoretical concepts concerning the mechanism of sleep and narcosis in general and concerning those produced by the electric factors in particular.

The visual investigation of the EEG's of rabbits and dogs subjected to electronarcosis, carried out earlier (K. A. Ivanov-Muromskiy and L. D. Murav'yev, 1959; K. A. Ivanov-Muromskiy, 1962; K. A. Ivanov-Muromskiy, M. S. Lobodyuk, V. G. Mel'nikov, D. M. Eppel', 1963), did not make it possible to evaluate with sufficient completeness the nature of the activity of the corticosubcortical elements of the brain.

The curves for the biopotentials of the cortex and of the subcortical formations were analyzed (thalamic nucleus, and hypothalamus and reticular formation of the midbrain). During the period of EEG recordings, the pulse current generators were turned off to prevent artefacts. However, in practice this did not affect the nature of the EEG's (I. S. Robiner, 1956, 1958; K. A. Ivanov-Muromskiy and L. D. Murav'yev, 1959). The authors (1962) and R. Knutson (1963) showed the possibility of recording EEG's during electronarcosis.

The examination of autocorrelograms and periodograms has made it possible to clarify a series of significant conditions for the variation of physiological lability of the brain neurons, which had escaped previous analysis or which could not be interpreted due to insufficient proof. The comparison of our results with other data refined the earlier hypothesis on the mechanism of electronarcosis (K. A. Ivanov-Muromskiy, 1953-1957), and it is now represented as a process of the selfregulation of the cortex through the subcortical formations by means of direct and feedback loops.

The report discusses the prospects of investigating the high frequency components of EEG's for the diagnosis of the state of the brain; the automation of electronarcosis; the application of several probability methods /5 in the analysis of the electrograms of various "levels" of the central nervous system; methods of coding the data of electrophysiological investigations, and for telemetering them to the electronic computer.

THE USE OF PUNCHED CARDS IN ANALYSIS OF PHONOCARDIOGRAPHIC MATERIAL

V. G. Mel'nikov

The work is concerned with the application of punched cards in the analysis of phonocardiograms of acquired cardiac defects. This topic is part of the general problem of establishing a cybernetics center for the needs of medicine. The punched cards in the form of a single document for the physician and for the machine will make it possible to mechanize and automate the processes of collecting, storing and analyzing medical information.

The analysis of the phonocardiographic material does not differ substantially from various other searches, whose purpose is to select useful information from a large number of different problems.

The work describes the punched card system for analyzing phonocardiographic information. A classification, nomenclature and terminology are developed. A dictionary is composed for the elements of the phonocardiogram for coding the initial material.

EQUIPMENT SOLUTIONS FOR THE ANALYSIS OF THE GENERATED REPLY

B. A. Fomin, V. G. Uvarov, S. M. Grigorovich and
A. G. Skripnikov

It is well known that the brain pertains to a class of "large systems" and the observation of all its parameters is not feasible at the present time. Because only individual variable parameters of this system are accessible to observation, many mechanisms of the brain have not been discovered to date. Therefore, the selection of the most informative variables of the system for purposes of investigation becomes particularly essential.

One of such characteristics for the brain is the induced reply to adequate and inadequate stimulation. A fine analysis of this reply is difficult, /6 because it is partially unfolded on the background of the "spontaneous activity" of the brain, which distorts, masks and sometimes conceals it completely. In this sense the isolation of induced replies of the brain from the background of the general EEG's is a special case of the basic problem of information theory--the transmission of communications in the presence of noise.

None of the methods developed in recent times for the detection of signals in noises, for example, the method of statistical hypotheses with the Neuman-Pearson or Val'da criteria, the optimum linear filtration using any of the operator's

$$\frac{du_c(t)}{dt};\quad \int_0^t \varphi(t)\,u_c(t)\,dt;\quad u_c(t-\Delta t);\quad au_c(t),$$

cannot be applied directly in this case. The problem is complicated by the fact that the induced reply is developed on a background of "colored" noise, which is correlated with the induced reply. A satisfactory solution is possible by imposing additional limitations on the isolated signal.

Two versions of a setup are proposed (analog and digital), to obtain an averaged induced reply with a suppression of all random components. Both versions have line-type transmission bands corresponding to the line spectrum of the periodic signal. This matching produces a large gain in the signal-to-noise ratio. The setups are sufficiently simple and can be manufactured by our industry.

As an illustration of the operation of the digital setup, the averaged reply of the visual region of the cortex of the large hemispheres of the brain are shown after the stimulation of different conductive structures of the visual system.

SIMULATION OF THE REORGANIZATION MECHANISM OF RECEPTIVE FIELDS

V. G. Uvarov

It is known that the functional unit of the retina is the receptive field, when the retina adapts itself to a definite light background the receptive fields are reorganized.

The purpose of the work is to produce a model of this phenomenon on the basis of morphophysiological data on the structure and functions of the retina as a whole and of its individual elements. The internal loops of the model are established in accordance with the morphology of the retina. The elements of the retina are divided into two definite classes based on certain criteria. The properties of the elements of one of these classes are /7
sufficiently well known and serve as the basis for simulation. The properties of the other have been much less investigated; therefore, their selection for the model is rather hypothetical and proceeds from the functioning of the retina as a whole.

The operation of such a model is examined when the input signal is varied. The model consists of a program block diagram for an electronic digital computor and serves to transform the input signal "background illumination" into a spatial time-pulse code. When such a code is present at the output of the model, it is necessary to scan the input signal in a manner similar to that carried out by the retina. This is accomplished by a special programming unit. The investigation of such a model will be useful in solving a series of problems associated with the reception and processing of optical information. With this model we can investigate the reception of an image by overlapping receptive units in the presence of scanning according to a definite law, the difference between moving and stationary images, etc.

A SYSTEM OF INPUT DEVICES FOR THE AUTOMATIC ANALYSIS OF PHYSIOLOGICAL CHARACTERISTICS BY MEANS OF AN ELECTRONIC COMPUTER

Ye. A. Shkabara, Yu. S. Rubashev and V. M. Kharchenko

In order to utilize modern mathematical methods and electronic computers to process and analyze biomedical experimental data, it is necessary to have special devices for coding these data and introducing them into the computer.

The authors developed a system of devices which makes it possible to record, during the course of the experiment, on magnetic tape the investigated physiological characteristics of the organism and then to introduce the experimental data obtained in this fashion into the electronic computer for analysis.

The input system may be used both for the analysis of the pulse characteristics (pulse activity of neurons) and for continuous characteristics (electroencephalograms, electrocardiograms, recordings of blood pressure, etc.).

The electric pulsation of neurons is recorded on magnetic tape in the form of successive rectangular pulses. The electronic digital computer is fed with binary numbers, which specify the distances between the successive pulses. The magnitude of these intervals is computed by a special counter of the input system, using standard time intervals.

Continuous indicators are recorded on the magnetic tape by using /8 pulse modulation with a carrier frequency of 10 kc. The counter of the input device measures the number of carrier frequency pulses during the standard intervals of time. Then these binary numbers, which are proportional to the amplitude of the recorded curve, are introduced into the electronic digital computer. In this case the input device performs two functions simultaneously: it serves as a demodulater and as an analog-digital converter.

The standard intervals of time may be obtained either by means of a special generator in the input device or by the simultaneous recording of time and of experimental data on the magnetic tape. This method eliminates errors which may arise due to the acceleration and detonation of the taped transfer mechanism.

The system uses a precision tape transfer mechanism and a magnetic tape 6.3 mm wide. The recording is synchronous and uses 5 tracks. One of these is used to record the stimulation used in the experiment, the others are used to record the pulse and continuous physiological characteristics, which are

subsequently analyzed separately and together, using an electronic digital computer programed accordingly.

The input system is connected to the electronic digital computer and is controlled by it during operation. During adjustment the operation may be autonomous and controlled from the individual panel. The total error of the input system does not exceed 3-4 percent.

The device was used to analyze various physiological characteristics during the period of 1963-1964, using the "Kiev" electronic digital computer.

THE APPLICATION OF MATHEMATICAL METHODS IN ANALYZING CERTAIN PHYSIOLOGICAL CHARACTERISTICS

M. A. Kulikov and Ye. A. Shkabara

A study of the interaction of processes which take place in a living organism requires a study of the dynamics of modern physiology and medicine and the processing of a large amount of stationary and transient information.

With modern mathematical methods and by automation of information collection and processing, taking into account the special nature of the formulated problems, we can obtain reliable data on the variation in the parameters of these processes.

Some experience has been accumulated in the solution of such problems by the Physiological Cybernetics group of the Institute of Physiology of AN UkSSR. This experience includes the following:

1. The automatic analysis of the disruption of cardiac rhythm and /9
the amplitude-time interpretation of the electrocardiogram.

A strip of the electrocardiogram was analyzed for a period of 4-5 sec by means of the "Kiev" electronic digital computer. A special algorithm and program were prepared for this purpose. As a result of the analysis the amplitude-frequency characteristics of the notches and the intervals of ECG's were printed out, as well as the characteristics of the notch form P and one or several of the 13 possible diagnoses for the disruption of cardiac rhythm or a signal showing the necessity of continuing the investigations. An analysis of a series of ECG's has shown good correlation between the results and the data obtained by manual interpretation as well as a substantial economy of time (Kulikov, Sledzevskaya, 1962).

2. Autocorrelation, intercorrelation and spectral analysis of the electroencephalogram.

Sections of the EEG's taken from different regions of rabbit cortex were investigated for the purpose of determining the degree of assimilation of the rhythm produced by light stimulation. Sections of EEG's obtained from different regions of the cortex before and during stimulation were introduced into the machine. The machine conducted an analysis in accordance with a specially prepared program and printed out the graphs of autocorrelation, intercorrelation and spectral functions. The analysis of the result showed the suitability of these methods for determining the degree of assimilation of the forced rhythm (Kulikov, Khozyainova, Zlatin, 1964).

3. The determination of the degree of synchronization of two or several regions of the EEG's.

The numerical factor characterizing the degree of synchronization of two regions of the EEG in the process of developing a conditioned reflex in a dog was determined. The investigated section of the EEG's was introduced into the electronic digital computer, which printed out the desired quantity. A section of the EEG's, 25 cm long, was analyzed by the machine in less than 1 min with a high degree of accuracy (Yarovitskiy, Dumenko, 1963).

4. The mathematical analysis of the pulse activity of central neurons.

The electronic digital computer was used to investigate the regularity of central neuron pulsations for the purpose of obtaining the characteristics of their backgrounds and induced activity. The impulse activity was considered as the nonstationary case of the flow of homogeneous events with a periodic driving function. The recording on the magnetic tape of the pulse activity of cat neurons was introduced into the computer by using the universal input device developed by Shkabara and Rubashev (1963). The intervals of time between the successive pulses before and after stimulation were examined. It was established that there is a stationary distribution of pulse intervals for background activity. A clear grouping of the pulse generation period and its variation under stimulation was established. The method of superposition was used to obtain a clear isolation of neuron reply to stimulation /10 (Yarovitskiy, Preobrazhenskiy, Velikaya, 1963; 1964).

5. Analysis of psychological tests.

Several groups of healthy and psychic individuals were used to conduct a comparative analysis of their response to tests conducted using the speech-motorial method. The method of nonparametic statistics was used in the investigations because, due to the small number of observation and their large variability, the application of conventional methods of statistical analysis was unsuccessful.

By using the Van-der-Varden criterion it was possible to establish a substantial difference in the test results of various groups, to group the tests according to their degree of difficulty and to give an approximate quantitative evaluation of the number of errors of different types in each group (Kulikov, Rushkevich, 1963).

COMPREHENSIVE ANALYSIS OF EEG's

V. A. Nazarov

The complete automation of processing of experimental data by means of an electronic digital computer is an important problem in electroencephalography. To solve this problem V. M. Anan'yev proposed a multi-input amplitude analyzer to record information from electroencephalographs on a magnetic tape and a marker selector associated directly with the electronic digital computer. We developed special units to introduce this information to the "Ural-2" electronic digital computer from a marker selector.

It was possible not only to simplify and accelerate the processing of initial data substantially, but also to carry out a comprehensive analysis of EEG's, simultaneously with many test leads.

The comprehensive analysis of the EEG's includes the determination of a whole series of characteristics for each lead. The respective programs make it possible to obtain:

1. the total bioelectric activity for the investigated section of the EEG's and the bioelectric activity corresponding to different frequency ranges of EEG's;
2. the amplitude distribution of the entire section of EEG's and of individual frequency ranges;
3. the statistical distribution of intervals of the stress curve on the EEG's;
4. Indices characterizing the basic rhythm of EEG's;
5. the correlation coefficients of the respective channel with remaining leads.

It is also possible to obtain other characteristics of the electroencephalogram. /11

The results of the data processing are printed in digital form and then recorded as graphs and tables on special forms for further analysis.

METHOD OF ANALYSIS AND MAGNETIC RECORDING OF MANY ELECTROGRAMS FOR AUTOMATIC INTRODUCTION OF INFORMATION INTO THE ELECTRONIC DIGITAL COMPUTER

V. M. Anan'yev

There is no doubt that modern computer technology should be used for processing biomedical data. Computer technology becomes particularly significant in processing data obtained by measuring bioelectric potentials at many points. However, the existing methods for the simultaneous recording of many signals on the corresponding number of tracts have not made it possible, to date, to find simple methods for feeding such information automatically into an electronic digital computer.

The complexity of this problem is not associated with the difficulty of its solution in principle, which is entirely feasible with modern technology. It is much more difficult to find a complete, sufficiently simple and generally convenient solution which would facilitate wider use of computer technology. In all probability we have been su cessful in finding a satisfactory solution to the problem of the automatic introduction of information into computers by generally convenient means.

The universal multi-input analyzer of electrograms with magnetic recording consists of several basic units. The input commutating part of the analyzer makes it possible to collect all the input signals into one general track. There are 30 inputs in the constructed analyzer, which is a sufficient quantity for operating with the existing multichannel electrophysiological installations. The common track is supplied with transformed signals in the form of carrier pulses modulated in amplitude by the input signals.

The frequency of commutation determines the number of fixed ordinates per second per signal. During the period of one commutation cycle the common track contains a strict sequence of all signals, and this sequence is repeated periodically with a given frequency. The commutation frequency in the analyzer is 100 per sec, which makes it possible to record signals with a frequency up to 50 cps. All carrier pulses are fed in a definite sequence to the second unit of the analyzer--the amplitude-time converter. This converter is basic to a large number of modern amplitude analyzers. However, these analyzers are seldom used for the simultaneous analysis of a large number of electrograms; /12 this requires modification. In the amplitude-time converter the value of the carrier pulses is converted into the proportional duration of intermediate pulses. Depending on their duration, the output of the converter produces the corresponding number of counting pulses.

In our analysis of signal magnitude we achieve an accuracy of 3 percent with 30 different signal levels. The pulses are counted in the third unit of the analyzer--a five-digit flip-flop counter. The results are presented at the output of the analyzer in the form of a conventional binary code.

We introduced marker signals into the common code, so that during the subsequent machine processing there is a reliable separation of signals in the general mass of numbers. These markers are used to feed the code pulses into the memory of the machine. For the subsequent separation of cycles from each other we introduced auxiliary pulses into the common code--cycle markers which indicate the beginning of each cycle. All of these marker signals from the output of the analyzer are recorded on one track of magnetic tape.

The analyzer utilizes the type MAG-59 tape recorder, which after partial modification gives a recording density of approximately 25 pulses per mm.

To achieve automatic introduction of information into the memory system of the electronic digital computer, we developed a marker selector placed next to the machine. From the magnetic recording all elements of the common code are distributed along individual channels: cycle markers, signal markers and digital markers. The selector has seven output marker channels: cycle markers, signal markers and five-digit markers. These channels are connected to the special input device of the machine in order to introduce the information into the memory system in the form required for normal operation. For the "Ural-2" electronic digital computer a device of this type has been developed by V. A. Nazarov. A similar device can be constructed for other electronic digital computers.

We hope that the design of a multi-input analyzer will further the introduction of modern computer technology into general biomedical practice.

STANDARDIZATION OF SEVERAL METHODS OF PROCESSING BIOMEDICAL DATA BY MEANS OF AN ELECTRONIC DIGITAL COMPUTER

V. S. Grinev, E. V. Kalinina, R. N. Lazareva and N. A. Troitskaya

The statistical processing of experimental results is very significant /13 in biomedical laboratory practice. Although this processing is carried out using simple mathematical methods, it is time-consuming. The following problems occur most frequently:

1. comparison of two groups of objects on the basis of one or several quantitative symptoms (comparing standard values to experimental values);

2. evaluation of correlation between two quantitative or qualitative factors;

3. evaluation of the parameters of linear regression (the method of root-mean-squares).

The first problem may be solved by means of statistical criteria (Student, Wilkinson, x and X^2 criteria), the second and third are solved by the known methods of correlation and regression analysis.

For the continuous solution of these problems a group of standard programs for the "Ural-2" electronic digital computer has been prepared. Its use reduces the time of statistical analysis by a factor of several tens. The report presents simplified block diagrams of the programs and a series of examples of their application in medical investigations.

A SYSTEM OF EQUIPMENTS FOR THE QUANTITATIVE INVESTIGATION OF CARDIAC ACTION

V. A. Lishchuk, B. A. Beregovskiy and A. A. Gorbach

A system of equipments was developed for the purpose of determining experimentally the statistical characteristics of the heart operating in a state of automatism.

The 27 experiments conducted to date clarified many of the shortcomings of the physiological methods, the methods of analyzing data, the failure of existing equipment to satisfy the requirements of prolonged experiments and the recording of many variables and their quantitative processing.

The following equipment was used in the experiments: an EM2-01 manometer (two units), a "Galileo" manometer (one unit), a "Galileo" electrocardiograph, an IR-1 flow meter, thermistor thermocouples, an N-700 galvanometer oscillograph, US 48-02 recorder, a "Galileo" recorder and other devices.

The report gives an analysis of the deficiencies of the equipment and the requirements for new devices in accordance with our experience.

In addition, the problems of analyzing experimental data by means of electronic digital computers are considered.

THE EXPERIMENTAL DETERMINATION OF CHARACTERISTICS NECESSARY FOR THE OPTIMUM TREATMENT OF CARDIAC DISORDERS

N. M. Amosov, V. A. Lishchuk, O. I. Lissova,
S. A. Patskina and B. A. Beregovskiy

In the department of Biological Cybernetics of the Institute of Cyber- /14
netics of the Ukrainian Academy of Sciences theoretical and experimental work is being carried on to optimize the treatment of cardiac disorders and disorders of the circulatory system.

To solve this problem, it is most important to determine the algorithm of cardiac behavior, i.e., a mathematical description of the heart as a complete functional organ.

Work on the determination of the cardiac algorithm is divided into four stages:

1. the determination of the quality and quantity of the necessary information;
2. the extraction of this information in experiments;
3. the processing and analyzing of data;
4. the perfection of the model thus obtained by comparison with the prototype.

In view of the extreme complexity of the cardiac system as a whole it is not possible to simulate it experimentally at this time. Therefore, it is necessary to introduce limitations to make the formulated problem real. The authors have selected limitations under which only the automatic cardiac action is considered, without the control effect of the organism on the conditions of normal loading and without pathology. These conditions are realizable in the cardiopulmonary preparation.

Approximately 30 experiments have been conducted to date.

APPLICATION OF CORRELATION METHODS FOR THE INVESTIGATION OF THE CARDIOVASCULAR SYSTEM

K. P. Buteyko, Ye. N. Karyshev and B. S. Sinitsyn

Many phenomena which take place in the biological subjects have a random nature. Their variation is not entirely regular and a strict mathematical description may only be given by using the theory of random functions.

In particular, such random processes include electrocardiograms, /15
ballistocardiograms and phonocardiograms of man. The presence of deviations from the norm are correctly established, not from individual, rather random variations of the cardiograms but from their statistical characteristics, by using, for example, correlation functions.

For true statistical processing of cardiogram data special equipment is required--automatic correlators. Some of these make it possible to process graphic recordings, others are designed to determine the statistical characteristics directly during the experiment.

The use of correlators, which in their most developed form represent various data-handling systems, provides for high processing speed and high reliability in the criteria obtained for the state of the organism.

The application of statistical processing of ballistocardiograms by means of the known algorithm for determining the correlation has established criteria for the disruption of cardiac activity produced by mitral stenosis. The extent of the disease can be evaluated from the damping rate of the quasi-periodic component with a frequency 5-6 times greater than the frequency of cardiac pulsation.

The second possible criterion for the extent of analogous diseases is the damping rate of the peaks of correlation functions, which occur with a frequency equal to the frequency of cardiac contractions.

The utilization of this criterion may also be based on a simpler method of determining the probability of coincidence or noncoincidence of the signs of the test ballistocardiogram.

INVESTIGATION OF THE METHODS OF AUTOMATIC PROCESSING OF ELECTROENCEPHALOGRAMS

A. M. Zhdanov

Electroencephalography is one of the basic methods of investigating the activity of the central nervous system of man. The analysis of the electroencephalogram (EEG) is a rather complex process. Application of the electronic digital computer will make it possible to conduct an automatic analysis of EEG's.

The present paper considers three methods of automatically analyzing EEG's by means of an electronic digital computer.

The functional state of the brain may be investigated by recording and later automatically processing the EEG's. By automatic processing we mean the determination of the power of the biocurrents of δ-, α-, β-rhythms Pδ, Pα, Pβ.

The system for the automatic processing of EEG's consists of an /16
electronic digital computer with an input device for converting voltage to digital form and of a device to record the EEG's with a time-variable voltage $u = f(t)$ at the output, which is coupled with the device for converting voltage to digital form.

The powers of the δ-, α-, β-rhythms may be determined from the spectral density of the random function, which is the EEG. The spectral density may be determined by the following methods: indirect, direct, and using analog devices.

The essence of the indirect method consists of the fact that the spectral density

$$S_x(\omega) = 2\int_0^\infty R_x(\tau)\cos\tau\omega d\omega.$$

is obtained from the correlation function

$$R_x(\tau) = \frac{1}{\pi}\int_0^\infty S_x(\omega)\cos\tau\omega d\omega$$

The essence of the direct method consists of computing the coefficients of the Fourier series for the experimentally obtained EEG's over a finite interval T and the subsequent determination of the spectral density function $S_x(\omega_k)$

$$S_x(\omega_к) \approx \frac{1}{T}(a_к^2 + в_к^2),$$

where

$$a_к = \frac{2}{T}\int_0^T f(x)\cos\frac{к\pi x}{T}\,dx,$$

$$в_к = \frac{2}{T}\int_0^T f(x)\sin\frac{к\pi x}{T}\,dx.$$

If the spectral density is known, it is possible to determine the powers of the δ-, α-, β-rhythms by means of the following equation

$$P = \frac{1}{\pi}\int_0^\infty S(\omega)d\omega.$$

The use of analog devices for obtaining the spectral density is carried out in the following manner.

The EEG [x (t)] is applied to the input of the electric filter in the form of a variable dc voltage. The calculation of the spectral density is reduced to the determination of the random function dispersion y (t) at the output of the electric filter by the corresponding measurement of the electric current power /17

$$S_x(\omega_0) \approx \frac{d_y}{\Delta\omega} \cdot P.$$

These methods were used to develop algorithms for the analysis of EEG's.

The data on the automatic processing of these EEG's by direct and indirect methods are presented as examples.

The results are used to draw certain conclusions. A bibliography is included.

AUTOMATIC PROCESSING OF RECORDINGS CHARACTERIZING THE ACTIVITY OF THE RESPIRATORY AND CIRCULATORY SYSTEMS AND THE WORKING CAPACITY OF MAN

A. M. Zhdanov

In recent years digital computer technology has been widely /17
introduced for the automation of industrial processes in our country. Electronic digital computers are widely used in medicine and biology.

The characteristics of the respiratory and circulatory systems and of the working capacity of man are established by recording the corresponding physiological functions. During the analysis of these recordings there are many manual operations which require a considerable expenditure of labor. The application of the electronic digital computer for these purposes will make it possible to replace manual operations and to process the data automatically.

The functional state of the respiratory and circulatory systems and of the working capacity of man can be investigated by recording and subsequently processing the following: electrocardiograms (ECG); seismocardiograms (SCG); the data of pulmonary ventilation (PV); arterial oscillograms and pressure curves; electromyograms and dynamograms.

By the automatic processing of recordings corresponding to physiological functions we mean the automatic introduction of data into the electronic digital computer, the performance of necessary measurements and calculations of the parameters and criteria, and the printing of the results. The system for the automatic processing of recorded physiological functions consists of the following:

1. an electronic digital computer with an input which transforms voltage into digital form;

2. devices which carry out the necessary recordings, whose outputs /18
give the variation of voltage with time $u = f(t)$ and which are connected with the converter of voltage to digital form.

The following methods are used for the automatic processing of recordings: the method of successive probes and evaluations for the determination of characteristic points and a programed method for measuring the periods and amplitudes. The calculation of average values and their dispersion is carried out by means of recurrent formulas for mathematical expectation and dispersion. On the basis of these methods and equations, algorithms were developed for processing these curves.

As an example, data are presented on the automatic processing of ECG's. The results of the automatic processing of ECG's are compared with the results of their manual processing, using the same recordings. Conclusions are drawn from the results, and a bibliography is included.

APPLICATION OF THE DISPERSION METHOD FOR EVALUATING THE DATA OF PHYSIOLOGICAL AND PATHOPHYSIOLOGICAL INVESTIGATIONS

A. O. Navakatikyan

Under natural conditions the human and animal organism is subjected to the influence of many factors. During physiological, pathophysiological, toxicological and other investigations it is frequently necessary to clarify the interrelations and the interaction of various effects. By using correlation analysis we can obtain the quantitative nature of the relation between two phenomena. However, for the evaluation of the simultaneous action of several factors on the same process it is more rational to use the dispersion method of statistical analysis developed by R. A. Fisher. This method has been used in various areas of technology and biology; however, in physiological and toxicological investigations it is not used sufficiently.

In our laboratory, dispersion analysis is applied to the investigation of the simultaneous effect on the organism of various levels of temperature, oxygen concentration in the inhaled air and the degree of physical exertion. We established a measurable combined effect of these factors, in particular, the effect of oxygen action as a function of environmental temperature and physical exertion. In a series of cases the action of oxygen changed due to the effect of exertion. For example, under conditions of rest, when oxygen was inhaled, we noted increased perspiration, while during work it was substantially reduced. Under normal temperature, when oxygen was inhaled /19 (compared with atmospheric air), there was an increase in the skin temperature of the chest, while at a high temperature there was a decrease.

The investigation showed that when the organism is overheated, breathing oxygen may have a useful effect on the physiological processes (temperature regulation, cardiac activity and the state of the nervous system).

PROSPECTS OF USING MATHEMATICAL METHODS IN AVIATION AND SPACE MEDICINE

V. V. Parin, O. G. Gazenko and N. A. Chekhonadskiy

One of the characteristics of modern knowledge is the increased /19
use of mathematical methods in various fields of science, including biology and medicine. The use of these methods in aviation and cosmic medicine also shows great promise. The remoteness of the experimenter from the investigated subject and the presence of a substantial volume of biomedical information in the form of quantitative characteristics, showing the reaction of the biological subject on the comprehensive effect of external stimulations which sometimes approached the limit of endurance, require constant monitoring of the state of the organism.

It is of great interest to develop methods of monitoring the state of an organism, based on the use of the methods of the theory of identifying samples. In this case the origin of disorders in an organism will apparently be detected by an electronic digital computer, which has been specially "trained" for this purpose on the basis of a large amount of experimental data. In establishing the mathematical relationships between the external stimulations and the reaction of the organism, the methods of statistical dynamics developed in the theory of mathematical control may be applicable. These methods, which provide for the determination of a series of mathematical characteristics both of the external stimulation and of the subject itself, require the application of computer technology. In this connection it will apparently be possible to develop comprehensive methods of investigating biological subjects to examine the various interrelations between its organs and systems. We assume that this approach to the subject will perfect the methods of investigating biological processes and develop refined methods for their analysis. Apparently it will be possible to achieve the following:

1. a quantitative evaluation of the effect of external factors /20
on an organism, when the variations in the indicators of physiological functions are detected to a very small degree;

2. the calculation of physiological parameters which cannot be measured directly in a given experiment;

3. the development of methods and of special equipment for "compressing" information, i.e., the release of the channels of physiological equipment when the physiological indicators remain unchanged.

In a series of cases, when investigating the dynamics of the physiological functions of an organism, positive results may be obtained by using the methods of the theory of mathematical control, in particular, the integral criteria of properties for evaluating variations in a biological control system.

A great deal of attention should be given to the application of mathematical simulation in aviation and space medicine. Simulation, as it applies to biology, is not an exhaustive approach for investigating the biological process itself; however, it helps us to study some of the problems and to detect, even though very approximately, such laws as are unobserved in conventional experiments.

APPLICATION OF COMPUTER TECHNOLOGY FOR INVESTIGATING CONTROL SYSTEMS WHICH INCLUDE MAN

A. P. Kuz'minov, V. F. Onishchenko, Yu. A. Rozanov,
and M. M. Sil'vestrov

In the investigation of control systems, including man, the application of computer technology is most important. The success of control depends on the accurate development of its loop elements to take into account the psychophysiological possibilities of man. The problems of the rational selection of the structure of the manual control system and of the characteristics of individual elements, the study of the psychophysiological possibilities of the operator for executing control, the evaluation of the effectiveness of the entire system are unthinkable at the present time without the use of simulation.

In the investigation of control systems, which include man, the following basic problems can be solved by means of computer technology.

1. The analysis of the dynamics of a control system in which man participates. In this case the given equations of the object and of the control system are solved in the realtime scale, using analog computers to clarify the effect of basic parameters which control /21 the process.

2. The synthesis of control systems. This problem consists of selecting the structure of the variable part of the system, its characteristics and the values of its parameters, based on assigned technical conditions and the known characteristics of the operator.

3. The experimental investigation of system behavior under laboratory conditions. In these investigations part of the system elements are real, while the operation of another part of the elements is simulated by an analog computer according to preassigned equations using real-time.

4. The experimental investigations of system behavior under laboratory conditions, when various environmental and flight factors react on the operator (load factors, hypodynamia, isolation, noise, vibration, air mixture, illumination, etc.).

5. The experimental investigation of operator capabilities with different control system parameters and perturbations, when the control system operates under unique conditions.

6. The reduction of operator characteristics to the characteristics of the control system. This problem is solved by training the operator by means of trainers and simulators.

The investigation of the control systems, which include a human operator, require the application of a comprehensive recording of the parameters of control process dynamics, of response reactions and of the electrophysiological functions of the operator. The evaluation of the state of the psychophysiological stress of the operator during the control process must be carried out on the basis of the combined quantitative values of the physiological indicators, which carry basic information concerning the state of the operator, and also on the basis of the deviation in the controlled quantities from assigned values permitted by the operator, as he carries out various operations. For an operator who controls a more complex system, the indicators of bioelectric activity of high-frequency rhythms, galvanic skin reactions, cardiac activity and bioelectric activity of the muscles are higher, compared with the corresponding indicators recorded when the operator works with a less complex system.

In experiments with two control systems, the orientation of the same operator in a simulator, an increase in the bioelectric activity of high-frequency rhythms by a factor of 11 percent and an increase in the galvanic skin reaction by 56 percent were observed in the more complex version of the system.

During control of angular motion of one subject, the value of the bioelectric activity of high-frequency rhythms was 11.8 integral units during 10 sec of analysis, while the pulse rate was 70 strokes per min. During /22
the control of spatial relative motion of two subjects, each of whom had 6 degrees of freedom, the bioelectric activity of the high-frequency rhythms was 17.5 integral units, while the pulse frequency was 82 strokes per min.

Most of the control systems which utilize an operator are closed. To maintain a given control process, a definite amount of information must be circulated. Different control systems for the same process, which include an operator, may be compared with respect to the amount of information passing through the control loop during a definite period of time, in order to maintain the control process. Each of the criteria considered independently does not provide a complete evaluation of a control system utilizing a human operator. Therefore, it is necessary to develop a generalized criterion for evaluating a control system with a human operator. This should take into account all deviations of the control process coordinates, the integral evaluations of the transient process, the quantitative values of physiological indicators and parameters, characterizing the capacity of the operator to be trained and the evaluation of information processes in a closed system.

To evaluate a control system with a human operator, it is rational to use the following generalized criterion

$$J = \frac{\sum_{i=o}^{n} A_i}{\sum_{i=o}^{n} A_i \frac{x_i}{x_i \text{ dev}}},$$

where J is the generalized criterion;

$\overline{x_i}$ is the average value of the deviation of the control process parameters, of the indicators showing the emotional stress of the operator during control, of integral evaluations of the transient process, etc.;

$\overline{x_{i_{dev}}}$ is the average value of the deviation of the generalized control process coordinate as a function of the desired process coordinate during optimum control. When it is difficult to obtain the average value of the deviation during optimum control, we can take as $\overline{x_{i_{dev}}}$ the minimum average value of deviations obtained, when the parameters of the control system are varied;

A_i are weighting factors.

SIMPLIFIED METHOD OF MEASURING THE TRANSFER FUNCTION OF AN OPERATOR

A. A. Volkov

The application of the electronic digital computer in conjunction with /23 trainers opens up wide possibilities for the investigation of human activity in a closed controlled loop. A systematic presentation of the simplified method of measuring the transfer function of the human operator, augmented by the calculations of the author, are presented.

The simplified method is based on the use of a self-adaptive analog model, which is adjusted to simulate the operator, so that the root-mean-square error between the reactions of the operator and its analog model is a minimum. It can be shown that this condition is satisfied if the rate of change of the controlled parameter α in the model of the operator is proportional to the product of the error (y) and the partial derivative of the output signal of the model (u) with respect to the controlled parameter

$$\alpha = \kappa y \frac{\partial u}{\partial \alpha}$$

The number of automatically controlled parameters in the model is determined by the form of the transfer function.

Existing experimental data show that the action of the human operator in the closed control loop is well described by a transfer function of the following form

$$\frac{KT(1 + K_2 Tp)}{(1 + Tp)^2}$$

In this case the transient function of the human operator H (t) has the following form

$$H(t) = K_1 T \left\{1 - \left[1 + \frac{t}{T}(1 - K_2)\right] e^{-\frac{t}{T}}\right\}$$

The limits of measurement of parameters K_1, K_2 and T during the work of the operator under normal conditions are as follows: K_1, 1-20 1/sec; K_2, 0-9; T, 0.1-0.3 sec.

The transfer function of a human operator is not a stable quantity. It depends on a large number of conditions. As a rule we should point out that when the delay in the dynamics of the controlled object is large, the time constant of the operator is also large. It is of considerable interest to study the transfer functions of a human operator under experimental conditions.

APPLICATION OF THE ELECTRONIC DIGITAL COMPUTER TO THE OPERATIONAL EVALUATION OF THE EXTERNAL RESPIRATORY FUNCTION OF MAN

K. K. Shcherbakov

The examination of the volumetric and rate indicators of external /24
respiratory functions of man on the phase plane "rate-volume" illustrates the respiratory mechanism, and makes it possible to measure the complex of pneumotachometric data (the vital capacity of lungs, the current respiratory volumes, reserve possibilities, pulmonary ventilation, rate of respiration, etc.).

The manual processing of the "rate-volume" diagrams is carried out after the recording has been completed, and is associated with a considerable expenditure of time and tedious work, which does not always satisfy the requirements of modern experiments.

To obtain indicators for the external respiratory function under operating conditions a method was developed for the automatic processing of experimental data. The algorithm was simulated by means of an electronic digital computer, which printed out the continuous values of external respiratory parameters.

This method makes it possible to obtain numerical values for a series of parameters of the external respiratory function of man, with simultaneous visual observation of the maximum and continuous respiration loops on the screen of an oscillograph.

APPLICATION OF CERTAIN STATISTICAL INDICATORS FOR DETECTING PERSONS WITH CONCEALED FORMS OF STATOKINETIC DISORDERS

V. I. Kopanev

When people use transportation means, they are sometimes subjected to statokinetic disorders, characterized by nausea, vertigo, vomiting, etc. Persons with clearly defined statokinetic disorders as a rule are easily detected and given the necessary assistance. Concealed cases are more complex when the subjective and objective manifestations are insignificant (feeling of discomfort). In this case the detection of persons with statokinetic disorders is extremely difficult. Taking into account the experience with laboratory simulation of the concealed forms of rockiness by means of periodic application of the Coriolis acceleration, when some of the subjects exhibited /25 increased lability of a series of vegetative indicators (pulse rate, respiratory rate, etc.), we made an effort to evaluate these phenomena quantitatively. For this evaluation the experimental material was subjected to statistical processing. We determined the mean arithmetical values of (M), the root-mean-square values of (δ) and the deviations and coefficients in the variations of (C) (R. M. Bayevskiy, N. A. Chekhonadskiy, V. V. Bogdanov and others, 1964). The processing of results obtained with five subjects clarified the variability of the following indicators: pulse rate, respiration rate, RR interval and the amplitudes of the P notch in the ECG's.

The analysis of the information has shown that as a rule the values of the root-mean-square deviations and of the variation factors in subjects in a state of rockiness were greater than the initial values. A direct relationship was established between the degree of variability of physiological functions and the degree of rockiness. In cases of complaints of fever and feelings of discomfort, etc., the variability was more pronounced (three persons) than in the cases when the general feeling of the subjects remained unchanged (two persons). This observation is confirmed by the data of processing the RR interval of the ECG's in subjects K and N. In the case of subject K (more stable) the values of M, δ and C before rockiness were equal, respectively, to 0.85, 0.035 sec and 4.12 percent; after 1-5 min of rocking the results were 0.80, 0.052 sec and 6.5 percent; and after 15-20 min they were 0.82, 0.050 sec and 6.09 percent. In the case of subject N (with a lower statokinetic stability) the values of M, δ C before rocking were equal, respectively, to 0.91, 0.028 sec and 3.08 percent; after statokinetic stimulation the results after 1-5 min were 0.81, 0.048 sec and 5.92 percent, and after 15-20 min the results were 0.89, 0.088 sec and 9.94 percent.

Approximately the same results were obtained when other indicators were statistically analyzed: respiratory rate and the amplitude of the T notch in the ECG's. In controlled experiments (without the action of the Coriolis acceleration) the variability of the indicators was insignificant in the same subjects.

In view of these results we came to the conclusion that increased variability of physiological indicators may be considered in conjunction with other symptoms as an indicator of statokinetic instability and apparently is one of the basic symptoms for detecting cases of concealed occurrence.

The same results were obtained in an analysis of certain data from space experiments with cosmonauts during the orbits of Vostok.

The experience of using certain statistical indicators for detecting concealed forms of statokinetic instability again confirms the validity of a wide application of statistical and mathematical methods for the scientific analysis of biomedical information for the purpose of confirming and establishing new laws in biological processes.

MATHEMATICAL ANALYSIS OF BIOCHEMICAL DATA ON THE DYNAMICS OF CHOLESTEROL AND ITS SIGNIFICANCE IN CLARIFYING THE REASONS FOR AND DEVELOPING PREVENTIVE TREATMENT FOR ATHEROSCLEROSIS IN PILOTS

Yu. F. Udalov, A. G. Melikhova, A. S. Kontsov,
N. I. Mukhamedzhanov and V. A. Nazarova

Cardiovascular disease, particularly atherosclerosis, is one of the most frequent causes of disability and death. /26

The clarification of the reasons for the occurrence of atherosclerosis and the development of preventive treatment is particularly significant for the Air Force, because even the initial stages of the disease may serve as a basis for grounding pilots.

It has been established that atherosclerosis has several causes, particularly the disruption of cholesterol exchange.

For a series of years, in an effort to investigate this problem, over 2,000 pilots of the Air Force and of the Civil Air Fleet, as well as others, have been examined. Efforts were made to establish the effect of the following on the cholesterol exchange: diet, extent and type of flight activity, physical condition, hormonal activity of the cortex of the adrenal glands, and age. The following biochemical indicators were determined: the cholesterol level in the blood, the phospholipid content, excretion of urine with 17-ketosteroids and 17-hydroxycorticosteroids, vitamin exchange (the content of ascorbic acid in blood plasma, excretion with urine of ascorbic acid, thiamine, riboflavin, 4-pyridoxine acid and N_1-methyl nicotinamide).

In the analysis of these data the usual methods of statistical analysis were used with the calculation of the average quantities, the mean-root-square quantities, the average error and the difference of statistical reliability. By means of this analysis it was possible to clarify the law governing the increase in cholesterol level of the blood after flight. A reliable difference in the given reaction, depending on the extent of flight activity, was also established (conventional and test flight, flight under simple and complex conditions). These methods also established the difference in cholesterol level of various age groups and its higher level in flight personnel compared with other (grounded) professions.

A relation was established between the cholesterol level and the flight load factors, as well as flight specialty and functional duties in flight.

By using the correlation method it was possible to determine a substantial positive relationship between the change in cholesterol level in the blood, associated with flight activity, and the increased activity /27
of the cortex of the adrenal glands, whose biochemical indicator is the amount of secretion of 17-hydroxycorticosteroids and 17-ketosteroids.

The correlation method also produced results in clarifying the role of vitamin shortage in the genesis of atherosclerosis, and for establishing the basis of preventive treatment, which was later verified experimentally.

A relationship was established for the cholesterol level in the blood as a function of the physical state (first of all as a function of body weight and its deviation from the norm). However, the analysis of the data did not justify the initial expectations. This variation turned out to be much smaller than the relation between cholesterol level and the nature of flight activity.

All of the established laws may be of practical value in the preventive treatment of atherosclerosis in flight personnel. At the same time, we can make a positive statement that if this great amount of experimental material were subjected to machine methods rather than manual methods of processing data, the analysis would have been much more meaningful. It would have been possible to obtain a more definite concept of the magnitude of flight loading leading to a substantial disruption of cholesterol exchange, which in turn is very important for standardizing flight work.

The mathematical analysis of some biochemical data on a sufficiently scientific level is practically impossible without the use of machines to process the experimental data. An example of this may be the exchange of amino acid and the effect of diet and external factors on this exchange.

DYNAMIC CHARACTERISTICS OF THE CARDIOVASCULAR SYSTEM OF MAN AND THEIR UTILIZATION IN SPACE MEDICINE

A. D. Yegorov and N. A. Cheskhonadskiy

The problem of extracting a large amount of information from experimental data, when studying the problems of space medicine, is quite timely. One of the methods of interest from this point of view is the analysis of dynamic characteristics of controlling the autonomic functions of the test organism, which are determined from initial data contained in the results of experiments. Knowledge of control characteristics is quite important for evaluating the stability of the human organism as an automatic control system, when various flight factors act on it.

The transition of the organism under the action of external factors to a different functioning level, when the variation in the basic physiological /28 functions is within the allowable limits, apparently does not show that such external conditions are completely indifferent to the organism. When a series of strong external stimuli, usually investigated in aviation and space medicine, act on an organism it may be subjected to definite displacements which substantially change the dynamic nature of autonomic functions. However, such changes are not determined during the investigation of the processes of vital activity of the organism under purely static conditions. The dynamic deviations of the autonomic functions from their optimum adjustment may serve as the reason for functional disruptions in the organism, which do not appear immediately, but only after the organism remains under specific conditions for a certain period of time. The probable occurrence of these disruptions may be established beforehand by investigating the dynamic characteristics of the systems which control the autonomic functions in the human organism.

Dynamic characteristics of the system for controlling the pulse rate of some cosmonauts is presented at the instant of time when they go from increased gravitation to weightlessness. Analysis of these relationships shows that there is a substantial effect of weightlessness on the pulse-rate control system. In an effort to establish the effect of the neuroemotional factor, the results of experiments with animals in space were examined. The results obtained confirm that under weightlessness the reasons for the slow return of the pulse of the cosmonauts to its initial values are the changes in control, along with emotional factors. The transition from increased gravity to weightlessness changes the "parameters" of the control system.

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